Table 4.6.7 Estimated Time to Rehabilitate Hydraulic Drops No. 1 Through No. 5

Task	Duration
1) Hydropower Feasibility Study	4 months
2) Replacement Feasibility Study	4 months
3) Final Design *	8 months
4) Construction Phase	24 months
TOTAL TIME	40 months

* Does not include costs for design of hydropower machinery.

4.7 CANAL PRISMS

4.7.1 Structure Overview

The St. Mary Canal was construction between 1907 and 1915, and its original design capacity is 850 cfs. The canal is approximately 29 miles long and is an earthen, unlined, one-bank, contour canal. The original prism had the following parameters.

- 26-foot flat bottom trapezoidal section
- 2:1 (H:V) side slope fill sections
- 1½:1 side slope in cut sections
- invert slope of 0.00010 feet per foot (0.53 feet per mile)
- constructed of natural materials

The canal has been realigned and relocated in several locations since original construction. A significant relocation involved abandoning an elevated flume and placing the flow in a replacement canal between the outlet of St. Mary River Siphon and Spider Lake. Other relocations have been minor but warranted due to slope instabilities.

Cross drainage consisting of culvert structures under the prism exist at seven locations. All other drainages flow directly into the canal and are term stormwater inflow. Grassed overflow sections were constructed at several locations to accommodate excess inflows. The cross drains are listed below.

Table 4.7.1 Major Canal Cross-Drainage Structures

Cross Drain	Type	Constructed/Rehab.
Powell Creek	2 - 66-inch RCP	1995
Cow Creek	4.5' x 5' conc. Box	Original
Sta. 978+61	30-inch RCP w/CMP extension, 143 LF	Original
Sta. 1051+71	30-inch RCP, 140 LF	Original
Sta. 1093+94	30-inch RCP, 168 LF	Original
Sta. 1132+35	30-inch RCP, 143 LF	Original
Sta. 1195+65	30-inch RCP, 157 LF	Original

Note: RCP – reinforced concrete pipe
CMP – corrugated metal pipe

Eight bridges cross the canal section and range from county roads to private ranch accesses. The bridges are listed below, and two examples are shown in Figures 4.7.1 and 4.7.2.

Table 4.7.2 Existing Bridges Related to Project

Bridge	Location	Use
Babb	Sta. 66+65	Public
Kennedy Creek	Sta. 260+00	Public
Memorial	Sta. 395+20	Maintenance
St. Mary River	Sta. 501+00	Public
DeWolfe	Sta. 670+00	Private
Halls Coulee Wasteway	Sta. 884+93	Maintenance
Martin	Sta. 990+00	Public
Emigrant Gap	Sta. 1375+00	Public

Figure 4.7.1 Looking downstream at Martin Road Bridge (11/11/04).

Figure 4.7.2 Looking downstream at Emigrant Gap Road Bridge (11/11/04).

Other features include 8 drain turnouts which have been installed by BOR crews to facilitate maintenance and inspection activities. Two check structures, Kennedy Creek (Section 4.4) and Spider Lake, are used to control flows. Like the Kennedy Creek check, the Spider Lake check structure is inoperable. Two wasteways, Kennedy Creek (Section 4.4) and Halls Coulee, are used for emergency discharge of excess canal flows. However, the Halls Coulee wasteway is inoperable.

4.7.2 Existing Conditions & Deficiencies

General

Numerous deficiencies have been discussed by BOR staff and observed during our cursory inspections. They include, in part, the following:

- Reduced Capacity - The BOR reports that the canal has an available capacity of 850 cfs between the diversion dam and the inlet to the St. Mary River Siphon but only 670 cfs downstream of the river crossing. Based on current canals flows of 670 cfs, we did not observe sufficient and continuous freeboard upstream to support a claim of 850 cfs capacity upstream of the St. Mary Siphon. Canal capacity decreases have occurred because of prism degradation, sedimentation, erosion, encroaching upslope landslides, and settlement of fill sections. Figure 4.7.3 shows the effect of slope instability on the canal prism and reduced flow area, i.e. capacity.

Figure 4.7.3 Typical earth slide encroaching into canal prism and reducing capacity (11/11/04).

- Limited Access - Due to its inherent nature, i.e. one-bank construction, maintenance crews experience access limitations to the upslope portion of the canal. The existing maintenance road is narrow (10-feet wide) with many sharp curves and steep grades, making access with modern maintenance vehicles difficult and hazardous. The maintenance road has insufficient gravel surfacing, and maintenance crews express concerns of impassable roads during inclement weather. This poses a hardship for a manually inspected and operated system such as the St. Mary Diversion Facility.

- Inadequate Regulation - Both check structures and one of the two wasteways are inoperable. Again, for a manually operated system, this significantly curtails operational efficiency and response time in the event of an emergency. Presently, the canal operators attempt to anticipate, as much as 3 days in advance, any significant storm events so that diversion flows can be reduced to account for potential inflows which may or may not actually occur. In addition, the existing siphon inlets and outlets are not gated, which would allow maintenance to be performed on one of the siphons while water diversion continues, albeit reduced.

- Lack of Automation - The canal and its major structures lack automation, instrumentation and remote-control capabilities, which would improve efficiency, monitoring and safeguards in the event of emergencies. Automation should be incorporated at the dam and headgates and all checks and wasteways. Of course, operating checks and wasteways are a prerequisite to the future implementation of automation.

- Slope Instabilities - Slope movements and failures are occurring in both natural soils upslope from the canal prism and within the fill section (downslope bank). The 1½:1 original cut slopes and 2:1 fill slopes with an imposed canal pheratic surface are excessive for the nature of the fine-grained soils predominant downstream of the St. Mary crossing. Original construction techniques or limitations and inadequate surface preparation are most likely the main causes of fill embankment settlements and failures. Figures 4.7.3 and 4.7.4 show typical cut slope instabilities downstream of the St. Mary River Siphon. Figures 4.7.5 and 4.7.6 show typical cut and fill sections of the canal prism, respectively.

Figure 4.7.4 Looking downstream at typical canal prism. Note irregular cross-section, erosion of right bank, relatively recent armoring on left bank and slope failure in background (11/10/04).

Figure 4.7.5 One-bank canal section downstream of St. Mary River Siphon. This reach is excavated into bedrock and is stable (11/11/04).

Figure 4.7.6 Typical fill-section of canal at edge of coulee downstream of Spider Lake check structure (11/11/04).

- Seepage Losses - Seepage losses are observed along the entire length of the canal. However, the first 6 miles of canal most likely accounts for the majority of the seepage losses. Native soils consist of coarse alluvial fan deposits of Swiftcurrent and Kennedy Creek. Past the St. Mary River Siphon, soils are typically fine-grain glacial till and glacial drift soils. The BOR reports between 70 and 80 cfs is lost due to seepage between the diversion dam and the inlet of St. Mary River Siphon. Seepage losses reflect conveyance efficiency and contribute to fill section instabilities. Figure 4.7.8 shows typical material associated with alluvial fan deposits, which are prone to high seepage losses.

Figure 4.7.7 Rocky channel bottom decreases hydraulic capacity. This highly permeable material is typical of alluvial fan deposits associated with Swiftcurrent and Kennedy Creeks (11/11/04).

The following design-specific deficiencies were observed during our site inspections:

1. *Canal Shape.* Irregular cross-section over much of its length decreases flow capacity. At many locations only one embankment was installed during canal construction. The west side of the canal includes a left overbank at many locations that expand the canal to many times its normal width. Figure 4.7.8 shows an example of an irregular cross-section.

Each time that the canal shape expands or contracts it reduces flow capacity. All other things being equal, the canal capacity will increase if the shape is constant. In order to achieve a constant shape, a defined embankment would need to be installed on both sides along the entire canal (i.e., two-bank construction). Installation of a left embankment will require that local drainage (inflow) into the canal be addressed.

Figure 4.7.8 Example of irregular canal prism cross-section (11/11/04).

2. *Livestock Damage.* The canal right-of-way is not fenced. In general, livestock appears to have unrestricted access along the length of the canal. Over time the livestock can, and have, damaged the canal prism. Livestock increase the irregularity in canal shape as well as increase the roughness factor of the channel. Heavily used areas become more susceptible to erosion which further exacerbates the problem of inconsistent canal shape. Livestock tend to reduce canal efficiency and increase maintenance.

3. *Leakage.* Water leakage out of the canal has a negative impact in a number of ways. The canal size must be increased to account for water lost due to leakage. At some locations leakage can be detrimental to embankment stability. Significant leakage (70 to 80 cfs) has

been reported in the first 9 miles of the canal. Figure 4.7.7 shows typical material prone to high seepage losses.

4. *Local Runoff.* Some fairly large drainage areas contribute runoff directly into the canal. In general, little or no erosion protection has been provided at drainage culverts that divert water into the canal. As a result, severe erosion has occurred at numerous locations.

Figure 4.7.9 Severe inflow erosion at drainage culvert (11/11/04).

While addition of water to the canal may be beneficial under certain circumstances, it can be a major problem at other times. The canal should either be oversized with sufficient free board to carry the additional inflows with overflow or wasteway structures used for emergencies, or under-flow, cross-drainage beneath the canal should be provided. The former is preferred.

5. *Groundwater Piping.* Groundwater piping was evident at a few locations. At a couple of areas inside the canal, piping was obvious. This is indicative of upgradient groundwater entering into the canal. In general this type of piping should not be of serious concern. However, it would need to be addressed if a liner were to be installed inside the canal. At one

location groundwater piping was noted on the exterior embankment. This is of greater concern; since it is likely evidence that groundwater is leaking out of the embankment at a high enough rate that it is carrying sediment out of the embankment. Over time this could lead to embankment failure. An example of piping, most likely associated with construction of a drain turnout, is shown in Figure 4.7.10.

Figure 4.7.10 Piping on fill bank near existing drain turnout. Note areas of ongoing piping. (11/11/04).

6. *Sinuosity.* Numerous curves exist in the canal alignment. Each curve causes a loss of hydraulic momentum, which reduces the overall capacity. Minimizing the curves is recommended for any future canal improvements. Also, increased sinuosity increases both erosion and deposition within the canal prism. Erosion can increase instability issues of the canal side slopes. Examples of inefficient canal alignment (sinuosity) are shown in Figures 4.7.3 and 4.7.11.

Figure 4.7.11 Typical canal section showing sinuosity inherent to contour canals in rolling terrain (11/11/04).

7. *Roughness.* The roughness of the channel varies along its length and its cross section. Some areas are very rough and rocky while others are relatively smooth. The overbanks contain combinations of grass, bare soil, rocks, and brush. The BOR assumes a Manning's roughness of 0.0225 for new canals. An example of high surface roughness is shown in Figure 4.7.7.

8. *Slope.* The bottom slope of the canal is irregular. The invert has ups and downs that cause obvious ponding at low flows. This irregular slope decreases the efficiency of the canal in two ways. First it causes irregular cross sectional areas that are constantly creating contracting or expanding flow conditions. These conditions reduce canal capacity compared with a consistently shaped invert. Examples of an irregular slope are shown in Figures 4.7.1, 4.7.2 and 4.7.7.

9. *Access/Maintenance Road.* The existing access road exists only on one side of the canal. At three locations the road is discontinuous; at Kennedy Creek and at the two wasteways. The road follows along the canal and has relatively short radius bends that may make access with modern equipment difficult. The access road is rutted in some locations and very narrow at

some locations. The road, in many places, is reported by BOR staff to be impassable during inclement weather.

10. *Overflow Protection.* The existence of grassed overflow sections is reported (Engineering Appendix, April 11, 2003) but the locations of the overflows were not obvious. One may be present in just upstream of Memorial bridge. The location, size and design flow needs to be verified with any future improvements.

4.7.3 Rehabilitation Alternatives

The rehabilitation alternatives to be considered during the feasibility study and design phases for the canal prism and related structures include the following.

- ultimate canal capacity (preferred alternative)
- One-bank versus two-bank construction (two-bank preferred)
- reconstruction versus rehabilitation
- degree of realignment to improve efficiency, avoid slope instability, etc.
- degree of armoring
- seepage control and lining issues
- optimum types and ultimate locations of inline canal structures
- styles of gates on checks and wasteways
- level of automation, instrumentation and remote-control capabilities
- canal access crossings
- livestock fencing
- environmental and cultural restrictions

4.7.4 Estimated Rehabilitation Costs

Feasibility level costs were developed in the Engineering Appendix Report (April, 2003) for canal prism rehabilitation including reshaping and lining. Also developed in this report were costs for the following canal prism-related structures.

- Replacement of the seven culverts (required for canal and road widening)
- Landslide stabilization
- Replacement of Spider Lake check structure

- Replacement of existing drain turnouts and construction of new drain turnouts
- Replacement of Halls Coulee wasteway
- Widening of existing O&M roads, construction of new O&M roads in the Halls Coulee Siphon area, in the Drop Structure No. 1 area, and between Drop Structures No. 4 and 5.
- Replacement of 3 bridges
- Possible land acquisition specifically for reshaping of canal, raising canal banks, reducing slide slopes in slide areas, and offsetting new structures to allow for summer construction.
- Tree Removal
- Installation of fencing to protect any future canal lining and side slopes from livestock.

The cost estimates prepared by the BOR for the above items are dated on March 21, 2003. These cost estimates were reviewed and appear reasonable with several exceptions, the canal should be armored for protection against side channel erosion and bottom erosion during low flows. Also, canal reconstruction may be implemented in lieu of reshaping to improve efficiency and reduce impact of active landslides. Discussions with BOR staff on December 9, 2004 indicated that a final, two-bank canal prism is preferred for maintenance and efficiency. In our opinion, neither the BOR studies nor the BOR's canal prism cost estimates reflect the desire for two-bank construction.

Assuming construction would begin in the summer of 2007, it is appropriate to update these estimates by escalating the costs by 3% per year for four years. An additional cost for canal reshaping to include an allowance for additional armoring should be added. The following tables present the cost estimates originally prepared by the BOR projected to 2007 (with an assumed 20% additional allowance for additional gravel armoring, limited canal reconstruction and/or relocation and two-bank construction). Tribal fees (5%) were also added to the initial costs developed by the BOR.

Table 4.7.3 Cost Estimates to Rehabilitate Canal Prism Excluding Major Structures

Facility Component	BOR Cost Estimates - 2003		Projected Costs – 2007[1]	
	Q=850 CFS	Q=1000 CFS	Q=850 CFS	Q=1000 CFS
Canal Prism Reshaping and Lining	$33,000,000	$34,495,000	$47,000,000	$49,000,000
Landslide Stabilizations	$21,000,000	$21,000,000	$24,900,000	$24,900,000
Drain Turnouts	$750,000	$790,000	$886,500	$934,000
Powell Creek Culvert	$470,000	$480,000	$555,500	$567,500
Spider Lake Check	$1,140,000	$1,220,000	$1,407,000	$1,501,000
Cow Creek Culvert	$560,000	$560,000	$662,000	$662,000
Halls Coulee Wasteway	$1,400,000	$1,400,000	$1,714,000	$1,714,000
Culvert -Sta. 978+61	$210,000	$210,000	$248,500	$248,500
Culvert -Sta. 1051+71	$180,000	$190,000	$213,000	$225,000
Culvert -Sta. 1093+94	$210,000	$210,000	$248,500	$248,500
Culvert -Sta. 1132+35	$210,000	$210,000	$248,500	$248,500
Culvert -Sta. 1195+65	$190,000	$200,000	$225,000	$237,000
O&M Roads	$45,000	$45,000	$53,500	$53,500
Tree Removal	$320,000	$320,000	$378,500	$378,500
Land Acquisition	$54,000	$108,000	$64,000	$128,000
Fencing	$1,420,000	$1,420,000	$1,679,000	$1,679,000
TOTAL	$61,159,000	$62,858,000	$80,483,500	$82,725,000

(1) [(Adj. BOR Cost) * 1.1255] * 1.05

Recent canal rehabilitation projects (2000-2004) of similar nature and scope north of the Border have averaged approximately $1,600,000 per mile for two-bank construction. This price includes armoring, cross-drains, fencing and land acquisition, as well as studies, designs and construction administration. For this project, approximately 28 miles of canal would equate to $44,800,000. Subtracting this amount and the projected costs for landslide stabilizations ($24,900,000) from the total projected costs at 850 and 1000 cfs capacities leaves $10,783,500 and $13,025,000, respectively. In other words, the adjusted and projected BOR cost estimates for canal prism rehabilitation (minus landslide stabilizations) equates to approximately $1,985,100 and $2,065,200 per mile for 850 and 1000 cfs capacities.

The two largest influences on the costs of canal prism rehabilitation are the quantity and costs of additional ROW and the canal capacity, i.e. Preferred Alternative.

4.7.5 Rehabilitation Schedule

The majority of rehabilitation for the canal prism and related in-line structures, unfortunately, must be performed during the off-season. This will involve cold-weather construction and innovative techniques. Of course, mobilization, staging and stockpiling of materials can occur prior to winter shutdown of the canal. Only limited segments or reaches can be accomplished per construction season (irrigation off-season) to ensure uninterrupted water diversion and conveyance the following season. However, multiple reaches, whether the same or different contracts, can be performed concurrently.

It would be prudent to rehabilitate those reaches with the greatest capacity restrictions so that canal capacity could be increased incrementally each successive season. However, conventional canal rehabilitation is typically performed in an upstream to downstream fashion so that construction access is extended with each completed reach. We anticipate that complete canal prism rehabilitation may require 4 to 6 seasons.

4.8 SUMMARY

4.8.1 Overview

The majority of the structures comprising the St. Mary Diversion Facilities are in poor to very poor condition and are approximately 90 years, well beyond their design life. The continued degradation has resulted in a current diversion of 670 cfs, well below its original capacity of 850 cfs. In addition, maintenance costs, just to maintain minimal service, are escalating beyond the ability of the prime beneficiaries to pay them. Water shortages in the Milk River Basin have been largely attributed to the gradual deterioration of the St. Mary River Diversion Facilities. This has been echoed in many BOR and DNRC reports, and a representation of quotes is presented below.

- “The current system of canals and storage reservoirs supply irrigators with only one-third to one-half of the water needed for full crop production in a normal year.”